

# **Testing of Large Diameter Fresnel Optics for Space Based Observations of Extensive Air Showers**

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The JEM-EUSO mission will detect extensive air showers produced by extreme energy cosmic rays. It operates from the ISS looking down on Earth's night time atmosphere to detect the nitrogen fluorescence and Cherenkov produce by the charged particles in the EAS. The JEM-EUSO science objectives require a large field of view, sensitivity to energies below 50 EeV, and must fit within available ISS resources. The JEM-EUSO optic module uses three large diameter, thin plastic lenses with Fresnel surfaces to meet the instrument requirements. A bread-board model of the optic has been manufactured and has undergone preliminary tests. We report the results of optical performance tests and evaluate the present capability to manufacture these optical elements.

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## Testing of Large Diameter Fresnel Optics for Space Based Observations of Extensive Air Showers

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### Introduction

The JEM-EUSO mission uses a large telescope attached on the ISS to observe Extreme-Energy Cosmic Rays (EECR) incident on Earth's nighttime atmosphere that produce Extensive Air Showers (EAS). The Optics Module (OM) for JEM-EUSO consists of 3 2.5m diameter Fresnel lenses made from polymethylmethacrylate (PMMA). The unique OM design provides a large field of view ( $\pm 30^\circ$ ) and sensitivity to low photon flux phenomena in the near UV (330nm to 400nm) to adequate measure key properties of the EASs.

The present level of maturity of the OM has been achieved by designing and manufacturing test articles of the OM including 10cm, 20cm, 40cm and 1m. Recently, a 1.5m diameter breadboard model (BBM) of the OM, with a flight like design, was completed. The BBM includes two double-sided curved Fresnel lenses (front and rear) and a single flat lens (middle) with one Fresnel and one diffractive surface. Each lens was mounted in a frame structure and installed in a metering structure that provides proper spacing and alignment of the lenses, aperture stop and detector (Fig1). The testing completed thus far on the BBM includes transmission and focusing of the BBM. These key performance factors have been simulated using commercial optical design software tools and custom routines developed for the JEM-EUSO OM. An evaluation of the current manufacturing parameters used during the BBM fabrication was also completed.

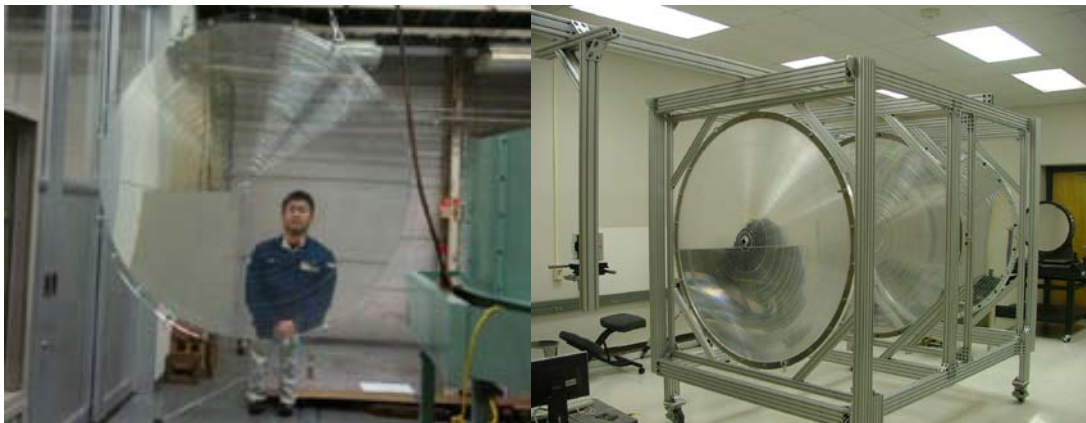


Fig 1. Picture of one lens (Left) and the BBM system assembled (Right)

### Transmission measurements

The transmission of the BBM lens was measured using a parallel beam produced by a parabolic mirror with a focal length of 2m and diameter of 60 cm. A light source pallet was assembled for transmission measurements using a laser diode (LD) with a wavelength of 405nm, focusing optics, a single mode optical fiber (<100 microns diameter) and an attenuation filter. The LD output was focused on to one end of the fiber optic and the other end was positioned at the mirror's focal point. A neutral density filter with OD 3.0 was used to reduce the intensity of the beam. The resulting collimated beam was circular with a azimuthally symmetric gaussian shaped intensity profile and a half intensity width of 12.3 cm. The intensity of the collimated beam was measured using a power meter (Newport model 918D-UV-OD3). The transmission of the front lens was measured with normal incidence at 5 positions along the radial direction offset from the optical axis: offset = 0 cm (optical axis), 10, 20, 30, 40 and 50 cm. These measurements included surface reflection losses at each surface, absorption within the lens material (nominal thickness of 1.5cm), scattering at the surfaces due to residual surface roughness resulting during the manufacturing process and the obscuration resulting from the several back-cuts that define the different Fresnel zones on the lens. The front lens performance was simulated to determine the best focal position to measure the transmitted power. Simulations show the focal length of the front lens alone is 580 cm. The image formed at this position is not a sharp point but is diffuse with the majority of light falling within a spot <1cm diameter. The transmitted power was measured at several different depths to identify the focal position. The resulting dependence was weakly dependent on the depth of focus within a few centimeters of the predicted optimal position. The results of the measured transmission are given in table 1. The measured transmission value of 69% at 30 offset should be compared with the results predicted by simulations incorporating the detailed characterization of the BBM lens that predicts ???.

Table 1 Transmission Measurements for Front Lens			
Offset	Incident Power	Transmitted Power	Transmission (%)
0	288	171	60
10	328	189	58
20	364	207	57
30	368	254	69
40	368	231	63
50	368	158	43

### Image focus performance

The focusing power of the BBM OM (all three lenses) was studied using a sub-aperture exposure to the collimated beam produced by the parabolic mirror as well as a full aperture exposure using an extended source. The sources used during testing included the LD at 405nm and a broadband xenon lamp together with narrowband filters. The emission lines of interest for atmospheric fluorescence produced by the EAS are at 337, 357 and 391nm. The filters used to evaluate the imaging performance included 340±5nm, 360±5nm, and 390±5nm. A single bandpass filter between 200-300nm (Schott UG1) was

also used (200-300nm) to determine the performance of the BBM over the full bandwidth. A digital camera produced by Photometrics SensSys is used to record images produced by the BBM at the predicted position of the focal plane. Optimization of the JEM-EUSO instrument has led to a curved focal plane design. The CCD is mounted on a 2 dimensional stage with travel of 5cm in the X and Z directions. This stage is then mounted to a 540cm (???) swing arm that matches the radius of curvature of the focal plane. This setup provides adequate flexibility to investigate the BBM imaging performance. The central element of the CCD is a Kodak 1401e chip with square pixels 6.8 microns on a side. The full array has 1317x1035 pixels and covers an area 9x7 mm<sup>2</sup>. The integration time for each exposure is controlled by a computer and is adjustable from 25 milliseconds to several minutes.

The JEM-EUSO science objectives require an image resolution of less than 5mm with a design goal for the OM to achieve <3mm. Simulations predicting the performance of the current OM flight design are shown in Fig 2. Images and results recorded during testing of the BBM are shown in figures 3-5. A composite image formed by adding images formed from the principal atmospheric fluorescence lines represented here by spike filters at 340, 360 and 390nm with the collimated xenon source in a sub-aperture exposure results in an RMS image width of 2.4 mm. The width for just the 360nm image alone was 2.3mm.

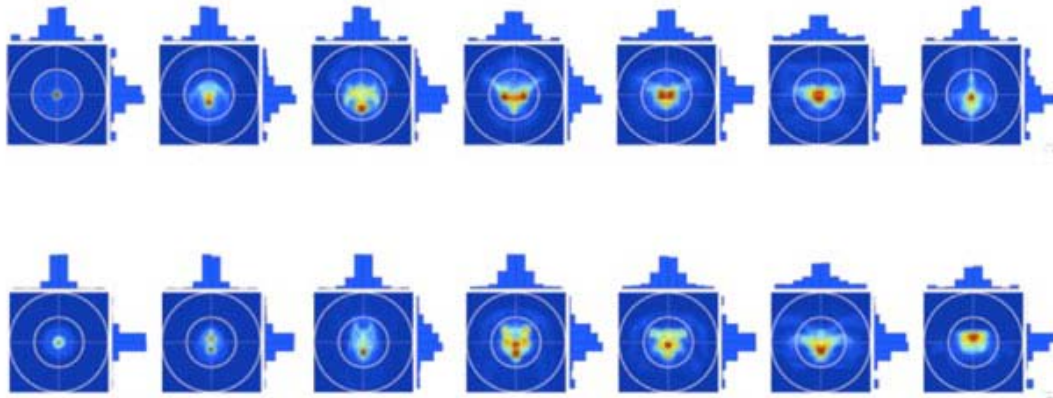


Fig 2. Simulated performance of the JEM-EUSO OM using the current flight design. The columns show the predicted image at 0°, 5°, 10°, 15°, 20°, 25° and 30° for the 2010 baseline and advanced design. (Maybe we should show the BBM predictions instead?)

Full aperture testing of the BBM used the same sources but without the 60 cm collimator. For these tests the source was located a distance of 40m from the BBM. This setup provided a full exposure of the 1.5 m diameter lenses and produced an approximate parallel beam of light. Images were recorded for on-axis and tilted at 10° with respect to the optical axis. The resulting image size was 2.5 mm RMS for the on-axis image and 2.7 mm RMS at 10°.

### Surface Roughness

The roughness of the finished lens surface was measured using a replication process. A commercial replication clay, Reproclay, was applied to several locations of the BBM surface. After drying the molds were lifted off of the lens surface and measured by

a Wyko profilometer. A trace from one of the mold impressions of the surface is shown in Fig6. The surface roughness was studied at several locations and shows a current performance of ~40 nm RMS.

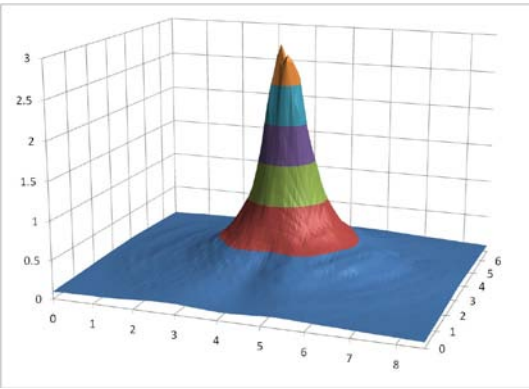


Fig 3 Composite Image

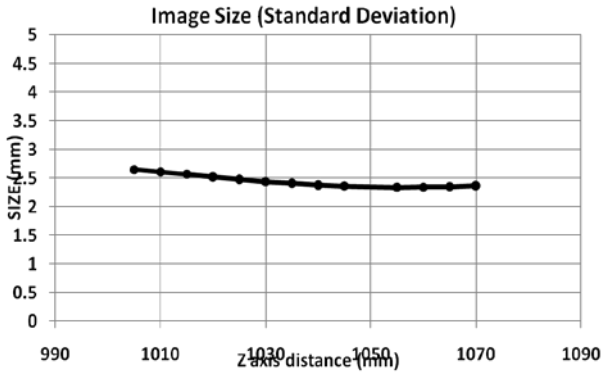


Fig 4 Image size versus depth for on axis measurement

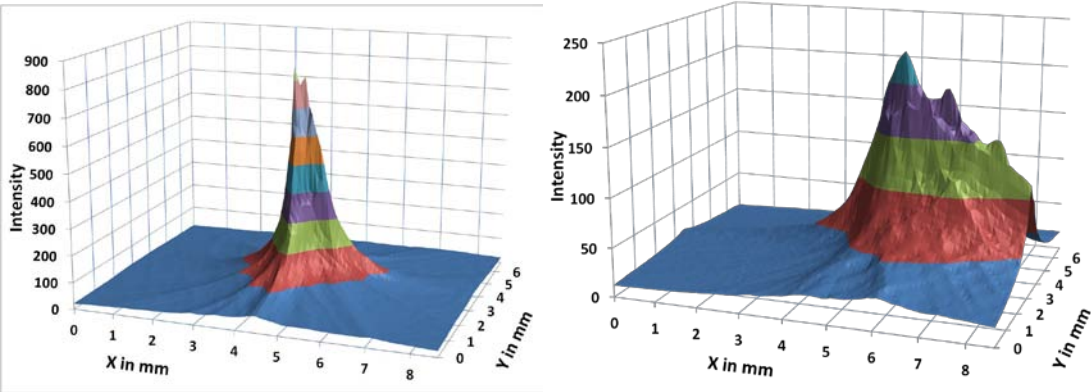


Fig 5. Full aperture images with the source on-axis (left) and at 10° off-axis (right). A bandpass filter transmitting between 300-400 nm was used to restrict the wavelengths from the xenon source.

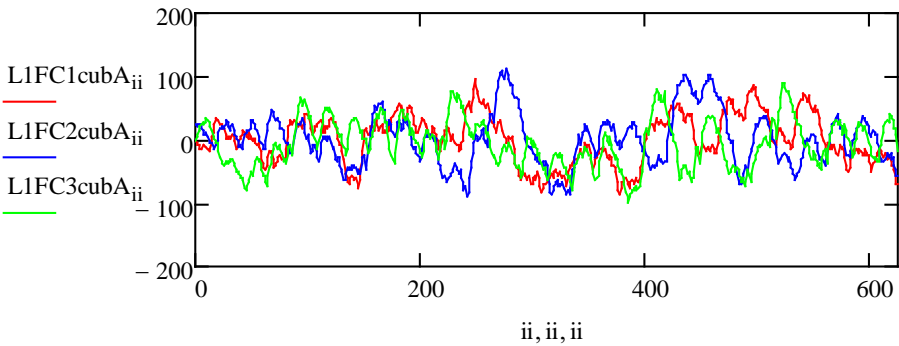


Fig 6. Traces of the optical surface of one lens after manufacturing.

## Summary

These preliminary tests on the BBM validate the technology and approach used to meet the OM requirements for the JEM-EUSO mission. The data shows that the BBM OM meets the expected performance as manufactured. Furthermore the performance meets or exceeds the instrument requirements for the scale model. A more thorough and complete set of tests have been proposed to NASA under the Explorer Program as part of a Mission of Opportunity. More detailed tests will likely provide the data necessary to understand the 2% increase in the focal length measured compared to simulations. The surface roughness analysis will help improve the manufacturing process to further reduce the surface roughness to help meet the goal of 20 nm RMS.